(12) **UK Patent Application** (19) **GB** (11) **2 257 671**(13)**A**

(54) **Method and device for the active control of the suspension system of a vehicle body**

(57) For the active control of a suspension system designed with a plurality of actuators (1-4), the position actual values (Z_1-Z_4) and the pressure actual values $(P_{actual1}-P_{actual4})$, and also the instantaneous longitudinal acceleration values (A_x) and the instantaneous transverse acceleration values (A_y) of the vehicle body are supplied to the computer of a status controller (11). First desired pressure values $(P_{desiredI1}-P_{desiredI4})$ for the individual actuators (1-4) are calculated in this computer, taking into consideration the respective significances.

A second desired pressure value $(P_{desiredII1})$ which corresponds to the simulation of desired spring/damper behaviour is again determined from the length actual value (Z_1) and the pressure actual value $(P_{actual1})$ for the individual actuators (1). The two desired values $(P_{desiredI1}, P_{desiredII1})$ associated with an actuator (1) are linked to form a resultant desired pressure $(P_{desired-res})$, and this resultant desired pressure $(P_{desired-res})$ is used, after comparison of desired value and actual value, to actuate supply and discharge valve mechanisms (1c) of the respective actuator (1).

Fig. 2

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Fig. 1

1 – VR	1c – PROPV–VR	1d ⟩ SV–VA
2 – VL	2c – PROPV–VL	2d ⟩ SV–HA
3 – HR	3c – PROPV–HR	3d ⟩ SV–VA
4 – HL	4c – PROPV–HL	4d ⟩ SV–HA

Fig. 2

Fig. 3

ignition on/RESET

START — ST101

Fig. 4

INITIALISATION — ST102

synchronous flag set? — ST103 — no

yes

desired action SWITCH ON? — ST104 — yes → SWITCH ON — ST109

no

desired action CONTROL? — ST105 — yes → CONTROL — ST110

no

desired action SWITCH OFF? — ST106 — yes → SWITCH OFF — ST111

no

desired action DIAGNOSIS? — ST107 — yes → DIAGNOSIS — ST112

no

desired action WAIT? — ST108 — yes → safety function — ST113

no

set back synchronous flag
set back watchdog — ST114

```
        ╭──────────────────────╮
        │    INITIALISATION     │──ST201
        ╰──────────────────────╯
                   │
                   ▼
        ┌──────────────────────┐
        │  SV-VA = OFF          │──ST202          Fig. 5
        │  SV-HA = OFF          │
        └──────────────────────┘
                   │
                   ▼
        ┌──────────────────────┐
        │ .Self-test            │
        │  - RAM - Test         │
        │  - ROM - Test         │──ST203
        │  - NVRAM - Test       │
        │  - ALU - Test         │
        │  - Watchdog - Test    │
        └──────────────────────┘
                   │
   ST204╲          ▼
        ╱ fault ╲──────── yes ──────────┐
        ╲       ╱                        │
            │ no                         │
            ▼  ┌ST207                     ▼  ┌ST205
    ┌──────────────────┐        ┌──────────────────┐
    │ set back watchdog│        │   SWITCH OFF     │
    └──────────────────┘        └──────────────────┘
            │                            │
            ▼  ┌ST208                     ┊  ┌ endless
    ┌──────────────────┐        - - - - -┊  │ loop
    │ initialize variable│                ┊  └
    └──────────────────┘         ┌────────┘
            │                    │
            ▼  ┌ST209            ▼
    ┌──────────────────┐   ┌──────────────────┐
    │ initialize hardware│  │  safety function │
    │  - .A/D converter │   └──────────────────┘
    │  - serial interface│          ┌ST206
    │  - timer          │
    └──────────────────┘
            │
            ▼
    ┌──────────────────────┐
    │ initialize interrupts │
    │  - time base (e.g.10 ms)│──ST210
    │  - A/D converter      │
    │  - diagnosis - interface│
    │  - timer (period length│
    │        measurement)   │
    └──────────────────────┘
            │
            ▼
    ┌──────────────────┐
    │ desired action   │──ST211
    │ = SWITCH ON       │
    └──────────────────┘
            │
            ▼
    ╭──────────────────╮
    │ end initialization│
    ╰──────────────────╯
```

SWITCH ON

Fig. 6

partial action RELEASE PUMP? — ST301 — no

partial action RELEASE SWITCHING VALVES?

input motor speed n-mot — ST302

input pressure P in pressure line — ST310

ST303

n-Mot >= n- idling - n-tolerance? — no

P >= minimum working pressure — ST311 — no..

yes

yes

ST306 — increment counter

ST304 — set counter = 0

increment counter

set counter =0 — ST312

ST314

counter reading > T-n- MOT ? — no — ST307

counter reading >= T - P ? — no — ST315

yes

yes

switch on magnetic clutch MGKP = ON — ST308

trigger actuators
PROPV-VR = CENTRE
PROPV-VL = CENTRE — ST316
PROPV-HR = CENTRE
PROPV-HL = CENTRE
SV-VA = ON
SV-HA = ON

ST309 — desired action = SWITCH ON partial action = RELEASE SWITCH VALVES

ST305 — desired action = SWITCH ON partial action = RELEASE SWITCH VALVES

desired action = CONTROL — ST317

desired action = SWITCH ON partial action = RELEASE PUMP — ST313

end of subroutine

Fig. 7

```
              ST351
  ┌─────────────┐
 (  SWITCH ON   )
  └──────┬──────┘
         │
         ▼
  ┌──────────────┐  ST352
  │increment counter│
  └──────┬───────┘
         │
         ▼
      ╱ counter  ╲        no
     ╱  reading   ╲───────────────────┐
     ╲  >T-ON-MIN ╱                    │
      ╲──────────╱  ST353              │
         │ yes                         │
         ▼                             │
  ┌────────────────────┐              │
  │ trigger actuators  │              │
  │ PROPV-VL= CENTRE   │  ST354       │
  │ PROPV-VR= CENTRE   │              │
  │ PROPV-HL= CENTRE   │              │
  │ PROPV-HR = CENTRE  │              │
  │ SV-VA = ON         │              │
  │ SV-HA= ON          │              │
  └─────────┬──────────┘              │
            │   ST355                 │
            ▼                         ▼
  ┌──────────────┐        ┌──────────────┐
  │desired action│        │desired action│
  │= CONTROL     │        │= SWITCH ON   │
  └──────┬───────┘        └──────┬───────┘
         │                       │
         │◄──────────────────────┘
         ▼
  ┌──────────────┐
 ( end SWITCH ON )
  └──────────────┘
```

Fig. 8

```
        ╭──────────────────╮
        │     CONTROL      │──ST401
        ╰────────┬─────────╯
                 │
    ┌────────────▼────────────────┐
    │       enter input data      │
    │ Z₁,Z₂,Z₃,Z₄,Pₐct₁,Pₐct₂,Pₐct₃,Pₐct₄, │──ST402
    │   Aₓ ,A_y ,(A_z1,A_z2,A_z3)  │
    │      in vector u_k+1[]       │
    └────────────┬────────────────┘
                 │
    ┌────────────▼────────────────┐
    │         fault test          │
    │    short-circuit to earth   │──ST403
    │ operating voltage short-circuit │
    │         plausibility        │
    └────────────┬────────────────┘
```

ST404 — fault? — yes —→ SWITCH OFF (ST405) —→ desired action = SWITCH OFF (ST406)

no

status controller:

ST408 — calculation of manipulated variables (influence) of current signals and of old 'status'

$$y_{k+1}[] = d[][] \cdot u_{k+1}[] + t_k[]$$

ST409 — compensation of non-linearities

$$y_{NL}[] = f(y_{k+1}[], ...)$$

ST410 — triggering of proportional valves

$$P_{des1} = y_{NL}[0]; \quad P_{des2} = y_{NL}[1];$$
$$P_{des3} = y_{NL}[2]; \quad P_{des4} = y_{NL}[3];$$

ST411 — calculation of new 'status'

$$x_{k+1}[] = a[][] \cdot x_k[] + b[][] \cdot u_{k+1}[]$$

ST412 — storage of new 'status' as old 'status'

$$x_k[] = x_{k+1}[]$$

ST413 — calculation of auxiliary variable t[]

$$t_{k+1}[] = c[][] \cdot x_k[]$$

```
        ╭──────────────────╮
        │   end CONTROL    │──ST407
        ╰──────────────────╯
```

Fig. 9

```
      ( SWITCH OFF )──── ST501

              │
              ▼
   ┌──────────────────────┐
   │ block switching valves│──── ST502
   │    SV-VA= OFF         │
   │    SV-HA= OFF         │
   └──────────────────────┘
              │
              ▼
   ┌──────────────────────┐
   │    fault display      │──── ST503
   └──────────────────────┘
              │
              ▼
   ┌──────────────────────┐
   │ set proportional valves│
   │   in centre_position   │
   │  PROPV-VL= CENTRE      │──── ST504
   │  PROPV-VR= CENTRE      │
   │  PROPV-HL= CENTRE      │
   │  PROPV-HR= CENTRE      │
   └──────────────────────┘
              │
              ▼
   ┌ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
   │ open magnetic clutch  │──── ST505
   │     if necessary      │
   └ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
              │
              ▼
   ┌──────────────────────┐
   │   desired action      │──── ST506
   │     = WAIT            │
   └──────────────────────┘
              │
              ▼
   ┌──────────────────────┐
   │  enter fault store    │──── ST507
   │     in NVRAM          │
   └──────────────────────┘
              │
              ▼
      ( end SWITCH OFF )
```

Fig. 10

a)

cycle time
(e.g.10ms)

$\Large\lightning$ ST601

(Timer-ISR)

↓ ST602

```
set
synchronous
flag
```

↓ ST603

(End ISR)

b)

undervoltage
eg ignition off

$\Large\lightning$ ST701

(NMI-ISR)

↓ ST702

‖ SWITCH OFF ‖

↓ ST703

(End ISR)

c)

pulse from
tachometer

$\Large\lightning$ ST801

(Timer-ISR)

↓ ST802

```
update
n-mot variable
```

↓ ST803

(End ISR)

d)

Analog/Digital-
conversion
terminated

$\Large\lightning$ ST901

(A/D-converter ISR)

↓ ST902

```
input position,
pressure of accel-
eration into
associated variable
```

↓

```
start A/D
conversion for
next channel
```
ST903

↓

(End ISR)
ST904

e)

receive byte at
serial interface

$\Large\lightning$ ST1001

(interfaces-ISR)

↓ ST1002

< diagnosis
already active > —no→

↓ yes

ST1004
```
evaluate
command byte
```

ST1003
< command byte
'switch on
diagnosis' > —no→

↓ yes

```
desired action
= DIAGNOSIS
```
ST1005

↓

(End ISR) ST1006

METHOD AND DEVICE FOR THE ACTIVE CONTROL OF THE
SUSPENSION SYSTEM OF A VEHICLE BODY

The invention relates to a method for the active control of
a suspension system of a vehicle body which is suspended on a
travelling mechanism comprising a plurality of wheels by a
plurality of actuators supplied with pressure fluid, with the
object of at least partially compensating rocking and
pitching movements of the vehicle body and optionally with
the further object of at least partially compensating
vertical movements of the vehicle body, the pressure in these
actuators being influenced by the supply of fluid and
discharge of fluid to and from these actuators as a function
of measured variables of the vehicle.

An active controller for a vehicle spring system is described
in EP-Bl 0 249 209, which successfully eliminates the
oscillations in various oscillation ranges and allows precise
control of pressure in the hydraulic cylinder using a control
valve. This object is achieved by a spring/damper unit
containing a variable pressure chamber, filled with working
liquid, a pressure source, which is connected to the
variable pressure chamber and delivers the pressure liquid
pressure-regulating means between the variable pressure
chamber and the pressure source for regulating the liquid
pressure in the variable pressure chamber, sensors which
monitor the body position and emit an indicating signal of
the body position, a controller, which receives the body
position signal and derives from it a control signal with
which the change in the position of the body is eliminated by
controlling the pressure-adjusting means.

The actively controlled spring system described in EP-Bl 0
249 227 very generally exhibits a system make up which is to
achieve the object already set out in EP-Bl 0 249 209. This
system comprises a spring/damper unit between vehicle body

and a wheel carrier in order to hold a wheel in a rotatable manner. The spring/damper unit contains a variable pressure chamber wherein the pressure reacts to the oscillations of the spring/damper unit. First pressure-regulating means are allocated to the variable pressure chamber and respond to the excitation of oscillations by the wheel carrier in order to regulate the pressure in said variable pressure chamber and to damp the oscillation energy of said spring/damper unit. Second pressure-regulating means are also allocated to the variable pressure chamber and respond to oscillations by the vehicle body in order to adjust the pressure in the variable pressure chamber and to eliminate the change of position of the body. The first pressure-regulating means comprise a store which is connected to the variable pressure chamber. First flow-preventing means are provided between the variable pressure chamber and the store in order to limit the flow of fluid and to damp the oscillation energy. Second pressure-regulating means comprise a pressure fluid source, a circuit which produces the connection to the fluid source, a valve, means for regulating the flow of the pressure fluid and a controller which detects the change of position of the vehicle body.

The solutions described in EP-B1 0 249 209, EP-B1 0 249 227 and also in DE-OS 38 13 695 relate mainly to the construction (hardware) of the overall system without providing practical statements on it. No statements are made about the overall control strategy and the practical design of the controller.

DE-OS 39 10 030 describes the pressure controlling means by means of which the objective can be achieved. Particular details are given about the method of incorporating the pressure controlling means (valve).

DE-OS 34 08 292 also describes an active spring system, details being given mainly about the controller itself, which

is designed as a status controller in this case. Sensors which carry out only position measurement are used.

DE-OS 37 38 284 describes an active travelling mechanism control system which relates predominantly to level regulation. The disturbance variables are derived exclusively from position measurement.

DE-OS 37 37 760 describes a method of controlling the volume of damping medium with the object of achieving optimum travel. Control is carried out as a function of sensors determining the instantaneous wheel power.

DE-OS 35 02 337 shows an active wheel suspension means which is to correct the rocking of the vehicle body by the supply and discharge of fluid to and from each spring chamber. The internal pressure in the fluid spring chambers, which is used as a rocking control variable, is mentioned as a possible measured variable. Simple pressure control takes place.

DE-OS 24 11 796 and DE-OS 36 44 931 describe similar systems to DE-OS 35 02 337. The state of loading of the vehicle is taken into consideration in DE-OS 40 17 223.

Similar systems with an identical aim are described, for example, in DE-OS 35 02 336 which gives closed/open loop control algorithms which meet the aim functionally via variable control times.

EP-A1 0 376 307 and EP-A2 0 386 623 each describe active wheel suspension control systems which are intended mainly to correct rocking and pitching movements. A controller unit controls the fluid supply and discharge such that pressure differences are compensated as a function of the status of the overall system. According to EP-A1 0 246 655, EP-A2 0 306 004 and EP-A2 0 284 053, the pressure in the hydraulic

system is also predetermined here by a controller as a function of sensor signals such that the centre of gravity of the vehicle body is controlled (change of pressure in each actuator). This procedure is deviated from in EP-A1 0 393 655 insofar as the system pressure merely has to lie within a predetermined range.

References to the use of the pressure in the actuators as control variables are given in EP-A2 0 392 507 and in EP-A1 0 398 308.

Very general statements about the actual control variable and about the correction variable (as target variable) are made in EP-A2 0 405 492, the objective merely being defined as keeping the correction variable constant.

EP-B1 0 193 744 describes an active wheel suspension system which describes the forces occurring between body and wheels via feedback processes.

EP-B1 0 219 866 provides a method of control according to attendant height differences between body and wheel owing to specific states of travel, reference also being made to control according to pressure.

Only EP-B1 0 223 098 describes a control strategy in which position as well as pressure are included.

DE-OS 39 04 922 shows a fail-safe or safe-life concept with a special build up of the hydraulic system by means of triggerable pressure control valves (three positions: increase pressure, reduce pressure, pressure constant).

The object of the invention is to provide a method and a device for controlling a vehicle suspension system which correct the pitching, rocking and optionally vertical

movements, dependent on the travel situation, of the vehicle body and can therefore, on the one hand, significantly improve the comfort of travel and, on the other hand, decisively positively influence the safety of travel.

According to the invention there is provided a method for the active control of the suspension system of a vehicle body which is suspended on a travelling mechanism comprising a plurality of wheels by a plurality of actuators supplied with pressure fluid, with the object of at least partially compensating rocking and pitching movements of the vehicle body and optionally with the further object of at least partially compensating vertical movements of the vehicle body, the pressure in these actuators and the length of these actuators being influenced by the supply of fluid and discharge of fluid to and from these actuators as a function of measured variables of the vehicle, characterised in that, using instantaneous values of the measured variables, namely the instantaneous position measured values and the instantaneous pressure measured values of all actuators, the instantaneous longitudinal acceleration measured values of the vehicle body, the instantaneous transverse acceleration measured values of the vehicle body and optionally instantaneous vertical acceleration measured values of the vehicle body, first desired pressure values are determined for the individual actuators in a status controller taking into consideration the influencing significances of the individual measured variables, in that these first desired pressure values in partial vehicle controllers allocated to individual actuators are used to control the fluid supply to or fluid discharge from the individual actuators.

Further according to the invention there is provided a device for carrying out the above method, comprising a

plurality of actuators between a travelling mechanism and a vehicle body, a high pressure supply for these actuators, a low pressure supply for these actuators, valve mechanisms for the selective connection of the individual actuators to the high pressure supply or the low pressure supply, a measured variable acquisition system for determining measured variables on the vehicle and a computer for obtaining actuation signals for the valve mechanisms, characterised in that the computer is connected to measured variable acquisition stations of the actuators, namely actual pressure and length acquisition stations of the actuators, also to longitudinal acceleration acquisition stations and transverse acceleration acquisition stations, and optionally to vertical acceleration acquisition stations of the vehicle body, in that the computer is designed to calculate first desired pressure values for the individual actuators on the basis of acquired measured values, and in that the outputs of the computer delivering these first desired pressure values serve for partial vehicle control.

During application of the method according to the invention and the device according to the invention, spring and/or damping behaviour is actively influenced with respect to vertical oscillations, rotary oscillations around the transverse axis (pitching) and rotary oscillations around the longitudinal axis (rocking). The term "active control of vehicle suspension means" means, in particular, that liquid is supplied to and discharged from the actuators and force is therefore actively transmitted between vehicle body and travelling mechanism.

If, in addition to the requirement of compensating rocking, pitching and optionally vertical movements, there is a requirement to produce desired damping/spring behaviour in

the individual partial vehicles by active control, it is
possible to proceed in that a second desired pressure value
is formed to simulate desired spring/damper behaviour of the
individual actuators for each of these actuators, in that the
first and the second desired pressure value are used to form
a resultant desired pressure value and in that this resultant
desired pressure value is compared in the respective partial
vehicle controller with the respective actual pressure value
of the associated actuator and in that the result of
comparison is used to control the fluid supply
to and fluid discharge from the respective
actuator. In particular, the resultant desired pressure
value of a partial vehicle controller may be formed by
cumulative overlaying of the respective first desired
pressure value and the respective second pressure value,
optionally with introduction of evaluating factors.

Refined control may be achieved in that earlier instantaneous
position and pressure measured values of the individual
actuators or/and earlier longitudinal acceleration measured
values or/and earlier transverse acceleration measured values
or/and earlier vertical acceleration measured values of the
vehicle body or/and the first timed derivatives of at least a
proportion of these measured variables associated with an
earlier moment of acquisition are additionally used to
determine the first desired pressure values for the
individual actuators. With periodic measured value
acquisition as earlier moment of acquisition, the directly
preceding moment of acquisition may be used in each case.
The timed derivatives may be determined, in particular, by
comparison of the instantaneous measured values and the
earlier measured values.

The measured values may be converted into first desired
pressure values for the individual actuators in that
at a moment of acquisition k+1, a measured value vector

$$u_{k+1}[]$$

is formed from the instantaneous position and pressure measured values, the instantaneous longitudinal acceleration measured value, the instantaneous transverse acceleration measured value and optionally the instantaneous vertical acceleration measured values, in that a manipulated variable vector

$$y_{k+1}[]$$

is determined from this measured value vector $u_{k+1}[]$ taking into consideration the influencing significances of the individual measured variables, according to the formula

$$y_{k+1}[] = d[][] * u_{k+1}[]$$

in which formula

$$d[][]$$

is a coefficient punch-through matrix representing the influencing significances and in that the manipulated variables, i.e. the first desired pressure values for the individual actuators, are derived from the manipulated variable vector

$$y_{k+1}[]$$

Non-linearities may be compensated in the manipulated variable vector.

If the above-mentioned refined control is employed, this may be effected in that when determining the manipulated variable vector $y_{k+1}[]$, an auxiliary variable vector $t_k[]$ is additionally taken into consideration according to the formula

$$y_{k+1}[] = d[][] * u_{k+1}[] + t_k[]$$

which auxiliary variable vector $t_k[]$ is derived from an earlier status vector $x_k[]$ according to the formula

$$t_k[] = c[][] * x_k[],$$

wherein, in this formula, $c[][]$ is a coefficient observation matrix which takes into consideration influencing significances of the earlier measured variables and the first timed derivatives thereof on the individual manipulated

variables, and wherein the earlier status vector $x_k[]$ is obtained from a corresponding earlier measured value vector $u_k[]$ and an even earlier, analogously formed status vector $x_{k-1}[]$ according to the formula

$$x_k[] = a[][] * x_{k-1}[] + b[][] * u_k[],$$

wherein, in this formula, $a[][]$ is a coefficient system matrix and $b[][]$ is a coefficient control matrix, and wherein the respective measured values and the associated first timed derivatives thereof enter the respective status vectors $x_k[]$, $x_{k-1}[]$.

A rocking moment distribution and the degree of rocking and pitching compensation may be taken into consideration at least in the matrix $d[][]$.

Specific desired control behaviour, for example according to the skyhook principle, may be taken into consideration in the matrix $c[][]$.

The method of control according to the invention functions only up to certain oscillation frequencies. Similarly, control may be maintained even when oscillation frequencies occur in the measured variables, in which the influencing of the actuators can no longer follow the determined manipulated variables. In this case, the vehicle suspension is no longer actively controlled but rather the vehicle suspension reacts as a passive suspension system, optionally as an adaptive suspension system. If the critical oscillation frequencies are fallen below again, active control inevitably adjusts itself again.

The actuators may be separated from the fluid supply and the fluid discharge in the event of faults in the system which may be determined by periodically effected diagnosis.

In this case, the actuators behave as passive actuators and
it is significant that the actuators produce soft suspension
behaviour in this state. This is desired because the road
holding of the vehicle, which is necessary for maintaining
lateral traction (safe-life behaviour) is maintained with
soft suspension behaviour. Therefore, control is preferably
carried out such that the softest suspension behaviour occurs
when the actuators are adjusted to the passive behaviour
(without fluid supply and without discharge) whereas harder
suspension behaviour is achieved with closed loop control.

To allow a return from an existing rocking position at the
transition to passive behaviour of the actuators and to make
the suspension behaviour even softer, it is proposed that a
fluid connection is produced between actuators associated
with a common axis of the vehicle. The actuators used may
be, in particular, hydraulic actuators which may be connected
selectively to a high pressure supply or a low pressure supply.

These hydraulic actuators may be combined with a respective
spring element, for example such that the spring element is
formed by a respective gas pressure store which adjoins the
hydraulic filling of the hydraulic actuator optionally via a
throttle.

The hydraulic actuators may be connected selectively via
directional signals to a high pressure supply (for example a
pump) and a low pressure supply (for example a tank).
Refined control is possible in that the hydraulic actuators
may be connected via a respective proportional value to a
high pressure supply or a low pressure supply, the
proportional valves optionally being followed by shut-off
valves. The proportional valves may be opened to different
extents as a function of the size of the difference between
pressure desired value and pressure actual value. To
enable this transition to be effected temporarily

in the event of a fault necessitating the transition to
passive suspension, shut-off valves may be provided in series
with the proportional valves.

At the beginning of the control period, that is roughly when
the vehicle starts up, initialisation of the control system
may be carried out by means of a subroutine. A self-test may
be carried out in the course of this initialisation so that
control is initiated on non-discovery of faults. Control may
be initiated by a subroutine (switch on) substantially such
that, in the scope of the "switch on" subroutine, the build up
of a predetermined minimum pressure in the supply lines to
the actuators is initially awaited and the valves allocated
to the individual actuators are placed in readiness for
control after this minimum pressure has been reached.

Alternatively, a "switch on" subroutine of this type may also
be designed in that in the scope of the "switch on"
subroutine there is initially a wait until a predetermined
driving speed of a pump allocated to the actuators is
reached, in that a magnetic clutch between the drive and
the pump is closed after this predetermined driving speed has
been reached, optionally with passage of a controlled slip
period and in that the valves allocated to the actuators are
placed in readiness for control after a predetermined minimum
pressure has built up in the supply lines.

On termination of travel, but also in the event of faults, a
"switch off" subroutine may be carried out, in the course of
which the individual actuators are separated from the high
pressure supply and the low pressure supply. Fault
conditions may be entered into a fault store for fault
diagnosis to allow subsequent recognition of the fault and
its elimination in the case of a disconnection of the active
control due to fault recognition.

The control software is designed such that it is essentially possible to distinguish between four phases which each contain differentiated subfunctions and therefore trigger different actions as a function of the current operating state:

1) Initialisation:

The initialisation phase relates to the microcomputer unit and its peripherals and comprises mainly a hardware and software self-test and the production of defined starting states (setting of system variables). The initialisation is carried out directly after the ignition has been switched on or a system reset and therefore guarantees fault-free "run up" of the electronic system (hardware and software). The directional valves or any shut-off valves connected in series with proportional valves are checked for closure and are closed if necessary in order to establish a defined starting state for accelerating the system.

2) Switch on:

The first information and therefore active connection between microcomputer unit (software/hardware) and the hydraulic system is now produced. A minimum supply pressure in the hydraulic system is produced by triggering the valves and the pump.

3) Control:

The cyclic processing of the control algorithm represents the normal state of the operating behaviour of the overall system. Sensor signals are input in the control algorithm and are processed accordingly. Position control is subordinated to pressure control in the controller designed as a status controller. The control strategy also proposes that two control planes be produced, the higher priority plane being responsible

for the overall vehicle, the lower priority plane for the partial vehicle, in particular quarter vehicle, and therefore the respective actuators on the wheel. Overall, the controller is designed for a slowly acting system, further differentiations being made for different travel situations:

a) Straight travel: oscillations of the vertical body movement are corrected in a slow and active for frequencies of 0 to 10 Hz (to desired pressure);

b) Cornering: oscillations (rocking) are corrected in a slowly acting manner for frequencies of 0 to 5 Hz (to desired pressure);

c) Acceleration: oscillations (pitching) are corrected in a slowly acting manner for frequencies of 0 to 5 Hz (to desired pressure).

For frequencies lying outside the ranges mentioned under a) to c), active control no longer takes place - owing to the inertia of the overall system; instead, only a passive, optionally adaptive suspension system is simulated. However, the controller runs unrestrictedly under these conditions and corrects the system into a slowly acting state as soon as the oscillation frequencies fall into the ranges specified under a) to c) again. In addition to the described main functions, "control" additionally includes fault testing routines so that, in particular, serious hardware faults (short circuit to ground, short circuit to operating voltage and the like) may be detected and safe-life measures may be initiated.

4. Switch off:
    The most important function of the software component "switch off" is to be able to produce the safe-life

behaviour of the overall system at any time. In this sense, the valves are set to "dead", i.e. the actuators are separated from the connection to the high pressure supply and the low pressure supply so that safe-life behaviour is achieved.

All in all, very soft ground adaptation of the vehicle suspension and therefore passively high comfort of travel is achieved via the hydropneumatic system and the disadvantages associated with the soft ground adaptation are eliminated by the active suspension control system in normal operation.

The invention also relates to a device for carrying out the control method comprising a plurality of actuators between a travelling mechanism and a vehicle body, a high pressure supply for these actuators, a low pressure supply for these actuators, valve mechanisms for the selective connection of the individual actuators to the high pressure supply or the low pressure supply, a measured variable acquisition system for determining measured variables on the vehicle and a computer for obtaining actuation signals for the valve mechanism.

In consideration of the object set out hereinbefore, it is proposed that the computer is connected to measured variable acquisition stations of the actuators, namely actual pressure and length acquisition stations of the actuators, also to longitudinal acceleration acquisition stations and transverse acceleration acquisition stations, and optionally to vertical acceleration acquisition stations of the vehicle body, that the computer is designed to calculate first desired pressure values for the individual actuators on the basis of the acquired measured values, and that the outputs of the computer delivering these first desired pressure values serve for partial vehicle control.

If further functions are to be taken into consideration in the partial vehicle controllers, for example a desired simulation of a spring/damper system, it is possible that the respective partial vehicle controller is connected to an actual pressure or/and a length acquisition station of the associated actuator and delivers a second desired pressure value, that an overlay unit for forming a resultant desired pressure value from the associated first desired pressure value and the associated second desired pressure value is also provided in the partial vehicle controller, and that a comparator unit for comparing the resultant desired pressure value and the actual pressure value of the respective actuator with this actuator, is also provided in the partial vehicle controller.

The invention will now be described by way of example with reference to the accompanying drawings in which:

FIGURE 1 is the hydraulic-pneumatic schematic diagram of a vehicle suspension means according to the invention,

FIGURE 2 is a schematic representation of a controller structure for the overall vehicle,

FIGURE 3 is a schematic representation of the controller structure for a quarter vehicle,

FIGURE 4 is a flowchart of a main program,

FIGURE 5 is a flowchart of the "initialisation" subroutine.

FIGURE 6 is a flowchart of the "switch on" subroutine,

FIGURE 7 is a flowchart of an alternative "switch on" subroutine,

Figure 8 is a flowchart of the "control" subroutine.

Figure 9 is a flowchart of a "switch off" subroutine.

Figure 10 shows flowcharts of various interrupt-controlled subroutines.

In Figure 1, a high pressure supply consisting of pump 12a, filter 12b, nonreturn valve 12c and pressure relief valve 12d is designated overall by 12. According to a four-wheeled vehicle, four actuators are designated by 1, 2, 3, 4. The actuators 1, 2 are allocated to the front axle and the actuators 3, 4 to the rear axle. Consequently, the actuators 1 to 4 are also designated in the following description according to the following conformability list:

$$1 - VR$$
$$2 - VL$$
$$3 - HR$$
$$4 - HL$$

Each of the actuators is allocated a pressure store 1b, 2b, 3b, 4b via a throttle 1a, 2a, 3a, 4a, more specifically these pressure stores are connected to the respective pressure chamber of the actuator.

The pressure chambers of the actuators 1 to 4 may be connected selectively to the high pressure supply 12 or to a tank 5 via proportional valves 1c, 2c, 3c, 4c, more specifically with a cross section which is adjustable as a function of a control signal. The proportional valves 1c to 4c are also designated in the following description according to the following conformability list:

```
1c  -  PROPV-VR
2c  -  PROPV-VL
3c  -  PROPV-HR
4c  -  PROPV-HL
```

Shut-off valves 1d, 2d, 3d, 4d which are also designated in the following description according to the following conformability list are arranged in series with the individual proportional valves 1c to 4c

```
1d )
   )
   )  SV-VA
   )
2d )
3d )
   )
   )  SV-HA
   )
4d )
```

The two actuators 1, 2 and the two actuators 3, 4 are connected by a respective transverse shut-off signal 7, 8. A respective throttle 7a, 8a is connected in series with the transverse shut-off valves. The transverse shut-off valves 7 and 8 belong to the shut-off valves SV-VA and SV-HA, respectively (switching valves front axle - switching valves rear axle) in the description. The shut-off valves 1d, 2d as well as the transverse shut-off valve 7 are adjustable by a directional valve 9 while the shut-off valves 3d, 4d and the transverse shut-off valve 8 are adjustable via a directional valve 10. The shut-off valves 1d, 2d, 3d, 4d are spring-biased such that they pass into the blocking position should the pump fail whereas the transverse shut-off valves 7, 8 are pretensioned such that they pass into the open position should the pump fail. This is desired because, during a failure of the pump and in other fault situations, the actuators 1-4 are to be separated from the high pressure supply 12 and the tank 5 and, furthermore, the actuators 1, 2 and 3, 4 belonging to a common axle are to be connected to one another throughout the respective

throttle 7a, 8a in such a situation. Pressure stores 9a, 10a are provided in the high pressure lines to the directional valves 9, 10 to compensate pressure variations.

The proportional valves 1c-4c are triggered by signals S1, S2, S3, S4 which are obtained in the manner described hereinafter. The signals are produced such that any rocking and pitching movements and optionally vertical movements of the vehicle body are at least partially compensated.

If the controller fails, for example owing to disconnection of the ignition or owing to the occurrence of a fault, the actuators 1-4 are separated from the associated proportional valves 1c-4c by the associated shut-off valves 1d-4d while the transverse shut-off valves 7, 8 are opened. This situation is known as safe-life behaviour. The vehicle suspension is soft in this case. An exchange of liquid between the actuators 1, 2 and 3, 4 associated with a common axle takes place during rocking owing to cornering.

Figure 3 shows that the control signal S1 is supplied to the actuator 1 via the proportional valve 1c, the shut-off valve 1d being omitted for the sake of clarity. The control signal S1 connects the actuator 1 to the high pressure supply 12 and the tank 5, depending on the sign. The throughput per unit time is adjusted as a function of the respective value of the signal S1 and for obtaining the signals S1-S4.

Figure 4 shows a higher-ranking status controller 11 which is common to all actuators 1-4. This higher-ranking status controller 11 is common to four partial vehicle suspensions PF1-PF4. The partial vehicle suspension PF1 is shown in Figure 3. The partial vehicle suspensions PF2-PF4 are similarly constructed. The actuator 1 according to Figure 3 belongs to the partial vehicle suspension PF1. This actuator 1 as part of the partial vehicle suspension PF1 delivers

measured value signals Z_1 and P_1 to the higher-ranking controller 11. Z_1 represents the respective length adjustment of the actuator 1 and P_1 the actual pressure of the actuator 1. The higher-ranking controller 11 accordingly receives measured values Z_2, Z_3 and Z_4 as well as $P_{actual2}$, $P_{actual3}$ and $P_{actual4}$ from the actuators of the partial vehicle suspensions PF2, PF3, PF4. The higher-ranking status controller 11 also receives the respective acceleration value A_x of the length acceleration from a longitudinal acceleration sensor, the respective acceleration value A_y of the transverse acceleration and a plurality of vertical acceleration values A_{z1}, A_{z2} and A_{z3}. The transverse acceleration value A_y can be measured directly similarly to the longitudinal acceleration value A_x. However, it is also possible to determine the transverse acceleration value A_y from the respective steering lock and the wheel status of the vehicle by computer, for example according to Ackermann's formula.

First desired pressure values $P_{desiredI1}$-$P_{desiredI4}$ are calculated in the higher-ranking status controller 11 from the measured values supplied to it for each of the partial vehicles PF1-PF4. The first desired pressure value $P_{desiredI1}$ is supplied to the partial vehicle controller PFR1. The same applies to the other first desired pressure values $P_{desiredI2}$-$P_{desiredI4}$.

In the partial vehicle controller PFR1, the first desired pressure value $P_{desiredI1}$ is supplied to an overlay unit or summation station B_1. A second desired pressure value $P_{desiredII1}$ which is also specific to the partial vehicle PF1 is further supplied to this overlay unit B_1. This second desired pressure value $B_{desiredII1}$ is calculated in a computer device R_1 taking into consideration the instantaneous length adjustment Z_1 of the actuator 1 and the instantaneous actual pressure value $P_{actual1}$ of the actuator

1. The computer R_1 is designed such that it simulates desired spring and damping behaviour of the actuator 1. A resultant desired pressure value $P_{desired-res1}$ is formed in the overlay unit B_1 for the partial vehicle PF1 by cumulative overlaying, optionally taking into consideration evaluating factors at least on one of the addends. This resultant desired value $P_{desired-res1}$ for the partial vehicle PF1 is compared with the actual value $P_{actual1}$ of the actuator 1 in a comparator unit or summation station K_1. The result of comparison produces a signal S_1 which is variable according to sign and value. This signal S_1 serves to trigger the proportional valve 1c.

The computer R_1 has been introduced here as a separate hardware component only for schematic illustration. The computer R_1 can actually, and preferably, represent additional software in the higher-ranking computer which is used for simulating the preferably used spring/damper characteristic and delivers the second desired pressure value $P_{desiredII1}-P_{desiredII4}$ for the respective partial vehicle PF1-PF4.

The higher-ranking status controller 11 therefore calculates, for controlling the proportional valve 1c, the amount, i.e the first desired pressure $P_{desiredI1}$, which is responsible for compensating pitching movements, rocking movements and optionally vertical movements of the vehicle body. While the computer unit R_1 of the partial vehicle PF1 calculates the amount, i.e. the second desired pressure $P_{desiredII1}$ which is responsible for the actuator 1 behaving according to a desired damper/spring combination between travelling mechanism and vehicle body. Default values, for example the rocking moment distribution, the degree of compensation of rocking and pitching, the distribution of moment-generating forces at various wheels, can be predetermined in the higher-ranking status controller 11.

The group consisting of the computer unit R_1 of the overlay unit B_1 and the comparator unit K_1 can be interpreted as a partial vehicle controller PFR1.

If the known skyhook principle is to be employed, this is effected by appropriate software in the higher-ranking status controller 11.

Appropriate partial vehicle controllers are provided in the partial vehicles PF2, PF3, PF4.

The software components allocated to the computer unit R_1 and the corresponding computer units of the other partial vehicles, together with appropriate adaptation of the hydropneumatic system, are responsible for the soft ground adaptation of the vehicle suspension. The disadvantages of soft ground adaptation arising in certain travel situations (cornering, longitudinal cornering, longitudinal acceleration) are compensated by the active vehicle suspension control. The measured values z_1, $P_{actual1}$ may be determined by appropriate sensors.

The higher-ranking status controller 11 may be designed with a single-channel or multi-channel microcomputer unit or with a signal processor.

The longitudinal acceleration sensor intended to determine the longitudinal acceleration A_x is preferably arranged in the vicinity of the centre of gravity of the vehicle on the longitudinal axis of the vehicle. Any transverse acceleration sensor is preferably arranged in the immediate vicinity of the rocking axis of the vehicle, unless the transverse acceleration is determined from the respective steering lock angle and the speed of travel, for example by the Ackermann equation.

The vertical acceleration sensors used to determine the vertical acceleration A_{z1}, A_{z2}, A_{z3} are preferably arranged in the immediate vicinity of the actuators, i.e. in the corners of the vehicle body. All acceleration sensors are arranged as far as possible from sources of thermal radiation in order substantially to prevent distortion of the measured value. The position sensors serving to detect the longitudinal adjustment z_1, z_2, z_3, z_4 are arranged on the respective actuator, preferably in the piston rod.

The pressure sensors used to determine the actual pressures $P_{actual1}$, $P_{actual2}$, $P_{actual3}$, $P_{actual4}$ are arranged as closely as possible to the respective actuator, preferably in the actuator itself, optionally in the hydraulic lines to and from the respective actuator.

Figure 8 shows a flowchart of the control carried out by the higher-ranking status controller 11, i.e. the determination of the first desired values $P_{desiredI1}$, $P_{desiredI2}$, $P_{desiredI3}$, $P_{desiredI4}$.

Control is initiated according to step ST401. According to step ST402, the longitudinal measured values z_1-z_4, the pressure actual values $P_{actual1}$-$P_{actual4}$, the longitudinal acceleration value A_x, the transverse acceleration value A_y and optionally the vertical acceleration values A_{z1}, A_{z2}, A_{z3} are fed into the higher-ranking status controller 11, where a measured value vector $u_{k+1}[]$ is formed from these values. According to step ST403, a fault test is carried out, in particular with regard to a short circuit to ground, operating voltage short circuit and plausibility.

The fault test can also relate to rates of change of the measured values in order to eliminate outliers. A plausibility check can also be carried out in the context of the fault test in order to discover contradictions between

triggering of a proportional valve and corresponding measured value. If, for example, the pressure in an actuator drops even though the associated proportional valve is adjusted to liquid supply to the actuator, a fault must be present.

If the existence of a fault is established in step ST 404, it leads to termination of the "control" subroutine in steps ST 405 and ST 406 and there is a switch back to the main programme in step ST 407.

If it is found in step ST 404 that there is no fault, a manipulated variable vector $y_{k+1}[]$ is calculated in step ST408 according to the formula there. In this formula, $d[][]$ denotes a coefficient punch-through matrix representing the influencing significances of the individual measured variables on the manipulated variable vector. Furthermore, $t_k[]$ in this formula represents an auxiliary variable vector which will be described in detail hereinafter with reference to steps ST 409, ST 410, ST 411, ST 412 and ST 413.

In step ST 409, non-linear dependencies of the manipulated variable vector $y_{k+1}[]$ on the measured variables are compensated and a compensated manipulated variable vector $y_{NL}[]$ is formed.

In step ST 410, scalar values for the first desired value $P_{desiredI1}-P_{desiredI4}$ are obtained from the compensated manipulated variable vector $y_{NL}[]$.

In step ST 411, a status variable vector $x_{k+1}[]$ is obtained according to the formula there, $a[][]$ representing a coefficient system matrix and $b[][]$ a coefficient control matrix. In the formula for step ST 411, $x_k[]$ represents an earlier status vector which had been formed similarly in an earlier control period while $u_{k+1}[]$ has the meaning according to step ST 402. The measured values corresponding to the

respective moment of acquisition according to step ST402 and the first timed derivatives thereof enter status vectors $x_k[]$ and $x_{k+1}[]$.

According to step ST412, the new status vector $x_{k+1}[]$ is stored as old status vector $x_k[]$.

According to step ST413, the auxiliary variable $t_{k+1}[]$ for the next control passage is calculated by multiplication of the now old status vector $x_k[]$ with a coefficient observation matrix $c[][]$, which takes into consideration influencing significances of the earlier measured variables and the first timed derivatives thereof on the individual manipulated variables. The auxiliary variable vector $t_k[]$ mentioned in step ST408 was similarly calculated.

With control according to Figure 8, transverse jolts and longitudinal jolts can also be taken into consideration, i.e. the first time derivatives of the transverse acceleration and the longitudinal acceleration, so that the determination of the desired pressures $P_{desiredI1}, P_{desiredI2}$ etc. can be further refined.

The longitudinal acceleration may be derived from the throttle valve control, from the braking pressure or - by time differentiation - from the engine speed.

Pressure control valves can also be used instead of the proportional control valves 1c, 2c etc. shown in Figure 1, so that pressure control exists in the respective valve and special pressure sensors can be dispensed with.

The control process depicted in Figures 1, 2, 3 and 8 is part of a higher-ranking program sequence which is shown in Figure 4. The higher-ranking program is started in a step ST 101 after the ignition has been switched on. An initialisation

program which is described hereinafter with reference to Figure 5 is called according to step ST 102.

On completion of initialisation, fundamentally different subroutines may be called providing step ST 103 demonstrates that a synchronous flag is set, i.e. there is just one time pulse from an external timer.

For control, it is in fact necessary for the control algorithm to be called up at fixed intervals of time, for example every 10 ms. If this is the case, the content of a system variable "desired action" is checked in steps ST 104, ST 105, ST 106, ST 107, ST 108 to discover which subroutine is to be called up. According to the result of this check, the appropriate subroutine is initiated in each case in one of the steps ST 109 "switch on", ST 110 "control", ST 111 "switch off", ST 112 "diagnosis", ST 113 "safety function". The synchronous flag and a watchdog is set back in step ST 114. A reset is triggered at the status controller 11 by means of the watchdog when the watchdog is not promptly set back. During a reset, the main program is started again in step ST 101. The watchdog therefore serves to monitor the electronic device as the system is brought back into its defined starting position again during a disturbed program sequence.

A return is then made to step ST 103 and there is a wait until the synchronous flag is set the next time by the external timer. The interrogation of the system variables is then begun again.

The initialisation initiating the execution of the main program according to Figure 4 is carried out according to Figure 5. Initialisation is initiated in step ST 201. In step ST 202 the shut-off valves 1d to 4d (corresponding to SV-VA and SV-HA) are brought into the blocking position and

the transverse shut-off valves 7, 8 are simultaneously
brought into the connecting position. The closure of the
shut-off valves SV-VA and SV-HA guarantees a safe status even
when the electronic device is set back by a reset or the
ignition is to be interrupted during control.

Various self-tests are carried out in step ST 203, namely

> a RAM Test (read/write memory)
> a ROM Test (external EPROM)
> a NVRAM Test (non-volatile memory)
> an ALU Test (arithmetic logic unit) and
> a Watchdog Test.

A decision is made in step ST 204 as to whether a fault has
been detected in one of the tests. If a fault has been
detected, the electronic device may not be set into operation
and the "switch off" subroutine is called up in a step ST
205. The "safety function" is then called up continuously in
step ST 206 in an endless loop. The fault is displayed and
the status controller 11 continues running only in the self-
test loop.

If, on the other hand, it is discovered in the decision step
ST 204 that there is no fault, the watchdog is set back in a
step ST 207. Variables are then initialised in the higher-
ranking status controller 11 in a step ST 208, for example
the status vector $x_k[]$ and the auxiliary variable vector
$t_k[]$. The hardware is subsequently initialised in a step ST
209. The A/D converters following the measured value sensors
are initialised in the process. Any serial interfaces are
also initialised. Timers, for example a timer for the
synchronous flag, are also initialised.

Interrupts, namely for the time base, the A/D converter, the
diagnosis interface and the timer (measurement of period

length)   are initialised in a further step ST 210.   The
content "switch on" is then input into the system variable
"desired action" in step ST 211 so that this content may be
detected in the subsequent interrogation of the system
variables in the main program (see Figure 4) in step ST 101 and
the "switch on" subroutine may be called up in step ST 109.

Figure 6 shows a first possibility of the "switch on"
subroutine. It is determined in steps ST 301 to ST 303
whether the driving motor of the pump 12a has reached the
idling speed. If this is not the case, a counter is set to 0
in step ST 304. It is then ensured by means of step ST 305
that the engine speed is checked until it is established in
step ST 303 that the idling speed is reached.

If it has been established in step ST 303 that the idling
speed is reached, a specific period of time is awaited
according to step ST 306 and ST 307 and a check is carried
out during this period of time as to whether the engine speed
remains above the idling speed. If this is confirmed in step
ST 307, a magnetic clutch located between the driving motor
of the pump and the pump 12a is switched on in step ST 308.
Once the magnetic clutch is switched on, a condition for
opening the shut-off valves 1d to 4d (corresponding to SV-VA
and SV-HA) is satisfied according to step ST 309.

It is then established in steps ST 310, ST 311, ST 312, ST
313, ST 314 and ST 315 whether the pressure in the pressure
line reaches a minimum working pressure and has existed for a
predetermined time. If this is the case, the proportional
valves 1c to 4c (corresponding to PROPV-VR etc.) are set to
centre and the shut-off valves 1d to 4d (corresponding to SV-
VA and SV-HA) are brought into the opening position. Control
can therefore begin after step ST 317.

Figure 7 shows an alternative embodiment of the switch-on process. Once the "switch on" subroutine has started in ST 351, a predetermined time is awaited in steps ST 352 and ST 353 and it is assumed that the minimum pressure required at the beginning of control is available after this time has lapsed. The proportional valves 1c to 4c are then set to centre in a step ST 354 and the shut-off valves 1d to 4d are simultaneously brought into the opening position. Control can then begin in step ST 355. The switch-on program is therefore completed.

Figure 9 shows the "switch off" subroutine. If there is a switch-off command according to step ST 501, the shut-off valves 1d to 4d (corresponding to SV-VA, SV-HA) are switched to block in a step ST 502 and the transverse shut-off valves 7, 8 are opened. The existence of a fault is displayed, if applicable, in a step ST 503. The proportional valves 1c to 4c (corresponding to PROPV-VL etc.) are brought into the centre position in a step ST 504.

If a magnetic clutch is provided according to the diagram in Figure 6, this is opened in step ST 505. It is then ensured in a step ST 506 that the "safety function" subroutine is called up during the next run-through of the main program.

If there is a fault, the fault conditions are entered into the non-volatile memory NVRAM in the next step ST 507. The switch-off function is therefore carried out.

Various variations of the "safety function" subroutine are conceivable. In the simplest case, an endless loop is continuously run through without performing any actions on the vehicle, the hydraulic apparatus then being switched to separate the actuators 1 to 4 from the high pressure supply 12 and the low pressure supply 5 according to Figure 1.

The interrupt service routines shown in Figures 10a to 10e process external events almost continuously and asynchronously to the actual program execution, i.e. the main program is immediately interrupted in the presence of an interrupt signal, the desired interrupt subroutine is executed and the main program is continued at the point at which it was interrupted, on completion of the interrupt subroutine.

The interrupt subroutine for setting the synchronous flag is shown in Figure 10a. If there is an interrupt signal from an external timer in a step ST 601, which signal can be given, for example, every 10 ms, the synchronous flag is set in a step ST 602 and the interrupt subroutine terminated in step ST 603.

The subroutine 10b indicates that a non-maskable interrupt (NMI) is triggered in a step ST 701 if the voltage supply fails, that is an interrupt of highest priority. This leads to disconnection in a step ST 702, whereupon the subroutine is terminated in step ST 703.

According to Figure 10c, an interrupt subroutine to input the current speed is called up by the speed generator of the pump drive in a step ST 801 in the presence of an interrupt signal. The instantaneous speed is input into a variable n-Mot in step ST 802 and the interrupt subroutine is terminated in step ST 803.

The interrupt subroutine for inputting the position, pressure and acceleration measured values is shown in Figure 10b. If an interrupt signal of an A/D converter converting the analog measured signals into digital measured values exists in step ST 901, the digital measured values are input into associated variables in step ST 902 and analog/digital conversion for

the next measured variable is started in step ST 903. The
interrupt subroutine is terminated in step ST 904.

Figure 10e shows the subroutine used for fault diagnosis. If
an interrupt signal which had been input, for example via a
keyboard, or had been triggered by closure of a switch
provided for this purpose is received via the serial
interface, the "diagnosis" subroutine is commenced in step
1001. A diagnosis mode is initiated in steps ST 1002, ST
1003, ST 1004 and ST 1005 by a special command byte or a
complete command sequence. The diagnosis subroutine called
up in the main program (Figure 4) then reacts to further
command bytes. The interrupt subroutine is terminated in
step ST 1006.

CLAIMS:

1. Method for the active control of the suspension system of a vehicle body which is suspended on a travelling mechanism comprising a plurality of wheels by a plurality of actuators (1-4) supplied with pressure fluid, with the object of at least partially compensating rocking and pitching movements of the vehicle body and optionally with the further object of at least partially compensating vertical movements of the vehicle body, the pressure in these actuators (1-4) and the length of these actuators (1-4) being influenced by the supply of fluid and discharge of fluid to and from these actuators (1-4) as a function of measured variables of the vehicle, characterised in that, using instantaneous values of the measured variables, namely the instantaneous position measured values (Z_1-Z_4) and the instantaneous pressure measured values $(P_{actual1}-P_{actual4})$ of all actuators (1-4), the instantaneous longitudinal acceleration measured values (A_x) of the vehicle body, the instantaneous transverse acceleration measured values (A_y) of the vehicle body and optionally instantaneous vertical acceleration measured values $(A_{z1}-A_{z3})$ of the vehicle body, first desired pressure values $(P_{desiredI1}-P_{desiredI4})$ are determined for the individual actuators (1-4) in a status controller (11) taking into consideration the influencing significances of the individual measured variables, in that these first desired pressure values $(P_{desiredI1}-P_{desiredI4})$ in partial vehicle controllers (PFR1-PFR4) allocated to individual actuators (1-4) are used to control the fluid supply to or fluid discharge from the individual actuators (1-4).

2. Method according to claim 1, characterised in that a second desired pressure value $(P_{desiredII1}-P_{desiredII4})$ is formed to simulate desired spring damper behaviour of the

individual actuators (1-4) for each of these actuators (1-4), in that the first and the second desired pressure value are used to form a resultant desired pressure value ($P_{desired-res4}$) and in that this resultant desired pressure value is compared in the respective partial vehicle controller (PFR1-PFR4) with the respective actual pressure value ($P_{actual1}$-$P_{actual4}$) of the associated actuator (1-4) and in that the result of comparison (S_1-S_4) is used to control the fluid supply to and fluid discharge from the respective actuator (1-4).

3. Method according to claim 2, characterised in that the resultant desired pressure value ($P_{desired-res1}$-$P_{desired-res4}$) of a partial vehicle controller (PFR1-PFR4) is formed by cumulative overlaying of the respective first desired pressure value ($P_{desiredI1}$-$P_{desiredI4}$) and of the respective second desired pressure value ($P_{desiredII1}$-$P_{desiredII4}$), optionally with introduction of evaluating factors.

4. Method according to one of claims 1 to 3, characterised in that earlier instantaneous position and pressure measured values of the individual actuators (1-4) or/and earlier longitudinal acceleration measured values or/and earlier transverse acceleration measured values or/and earlier vertical acceleration measured values of the vehicle body or/and the first timed derivatives of at least a proportion of these measured variables associated with an earlier moment of acquisition are additionally used to determine the first desired pressure values ($P_{desiredI1}$-$P_{desiredI4}$) for the individual actuators.

5. Method according to claim 4, characterised in that, with periodic measured value acquisition as earlier moment of acquisition, the directly preceding moment of acquisition is used in each case.

6. Method according to claim 4 or 5, characterised in that the timed derivatives are determined by comparing the instantaneous measured values and the earlier measured values.

7. Method according to one of claims 1 to 6, characterised in that at a moment of acquisition k+1, a measured value vector

$$u_{k+1}[\,]$$

is formed from the instantaneous position measured values $(Z_1 - Z_4)$ and the instantaneous pressure measured values $(P_{actual1} - P_{actual4})$, the instantaneous longitudinal acceleration measured value (A_x), the instantaneous transverse acceleration measured value (A_y) and optionally the instantaneous vertical acceleration measured values $(A_{z1} - A_{z3})$, in that a manipulated variable vector

$$y_{k+1}[\,]$$

is determined from this measured value vector $u_{k+1}[\,]$ taking into consideration the influencing significances of the individual measured variables, according to the formula

$$y_{k+1}[\,] = d[\,][\,] * u_{k+1}[\,]$$

in which formula

$$d[\,][\,]$$

is a coefficient punch-through matrix representing the influencing significances and in that the manipulated variables, i.e. the first desired pressure values $(P_{desiredI1} - P_{desiredI4})$ for the individual actuators (1-4) are derived from the manipulated variable vector

$$y_{k+1}[\,]$$

8. Method according to claim 7, characterised in that non-linearities are compensated in the manipulated variable vector

$$y_{k+1}[\,]$$

9. Method according to one of claims 7 and 8, characterised

in that, when determining the manipulated variable vector $y_{k+1}[]$, an auxiliary variable vector $t_k[]$ is additionally taken into consideration according to the formula

$$y_{k+1}[] = d[][] * u_{k+1}[] + t_k[]$$

which auxiliary variable vector $t_k[]$ is derived from an earlier status vector $x_k[]$ according to the formula

$$t_k[] = c[][] * x_k[],$$

wherein, in this formula, $c[][]$ is a coefficient observation matrix which takes into consideration influencing significances of the earlier measured variables and the first timed derivatives thereof on the individual manipulated variables (first desired pressure values ($P_{desiredI1}$- $P_{desiredI4}$), and wherein the earlier status vector $x_k[]$ is obtained from a corresponding earlier measured value vector $u_k[]$ and an even earlier, analogously formed status vector $x_{k-1}[]$ according to the formula

$$x_k[] = a[][] * x_{k-1}[] + b[][] * u_k[],$$

wherein, in this formula, $a[][]$ is a coefficient system matrix and $b[][]$ is a coefficient control matrix, and wherein the respective measured values and the associated first timed derivatives thereof enter the respective status vectors $x_k[]$, $x_{k-1}[]$.

10. Method according to one of claims 7 to 9, characterised in that a rocking moment distribution and the degree of rocking and pitching compensation are taken into consideration at least in the matrix $d[][]$.

11. Method according to one of claims 9 or 10, characterised in that desired control behaviour, for example according to the skyhook principle, is taken into consideration at least in the matrix $c[][]$.

12. Method according to one of claims 1 to 11, characterised in that control is maintained even when oscillation frequencies occur in the measured variables, in which the

influencing of the actuators (1-4) can no longer follow the determined manipulated variables (desired pressure values).

13. Method according to one of claims 1 to 12, characterised in that the actuators (1-4) are separated from the fluid supply and the fluid discharge when faults occur in the system.

14. Method according to claim 13, characterised in that a fluid connection (7; 8) is produced between actuators (1, 2; 3, 4) associated with a common axis of the vehicle.

15. Method according to one of claims 1 to 14, characterised in that the actuators used are hydraulic actuators (1-4) which may be connected selectively to a high pressure supply (12) or a low pressure supply (5).

16. Method according to claim 15, characterised in that the hydraulic actuators (1-4) are combined with a respective spring element (1b-4b).

17. Method according to claim 16, characterised in that the spring element is formed by a respective gas pressure store (1b-4b) adjoining the hydraulic filling of the hydraulic actuator (1-4) optionally via a throttle (1a-4a).

18. Method according to one of claims 15 to 17, characterised in that the hydraulic actuators (1-4) may be selectively connected via directional valves or pressure regulating valves to a high pressure supply (12) or to a low pressure supply (5).

19. Method according to one of claims 15 to 17, characterised in that the hydraulic actuators (1-4) may be connected via a respective proportional valve (1c-4c) to a high pressure supply (12) or a low pressure supply (5), the

proportional valves (1c-4c) optionally being followed by shut-off valves (1d-4d).

20. Method according to one of claims 1 to 19, characterised in that initialisation of the control system by means of an "initialisation" subroutine (Figure 5) is carried out before commencing control.

21. Method according to claim 20, characterised in that a self-test (ST203) is carried out during initialisation and control (Figure 8) is initiated on non-discovery of faults.

22. Method according to claim 21, characterised in that control is initiated by a "switch on" subroutine (Figure 6; Figure 7).

23. Method according to claim 22, characterised in that in the scope of the "switch on" subroutine (Figure 7), the build up of a predetermined minimum pressure in the supply lines to the actuators (1-4) is initially awaited and the valves (1c-4c, 1d-4d) allocated to the individual actuators (1-4) are placed in readiness for control after this minimum pressure has been reached.

24. Method according to claim 22, characterised in that in the scope of the "switch on" subroutine (Figure 6) there is initially a wait until a predetermined driving speed of a pump (12a) allocated to the actuators (1-4) is reached, in that a magnetic clutch between the drive and the pump (12a) is closed after this predetermined driving speed has been reached, optionally with passage of a controlled slip period, and in that the valves (1c-4c, 1d-4d) allocated to the actuators (1-4) are placed in readiness for control after a predetermined minimum pressure has built up in the supply lines.

25. Method according to one of claims 1 to 24, characterised in that control is terminated by means of a "switch off" subroutine (Figure 9), in particular when the ignition is cut off or on detection of a fault.

26. Method according to claim 25, characterised in that the individual actuators (1-4) are separated from a high pressure supply (12) and a low pressure supply (5) in the course of the "switch off" subroutine (Figure 9).

27. Method according to one of claims 25 and 26, characterised in that in the event of a disconnection owing to a detected operating fault, the fault conditions are entered in a fault store for the purpose of fault diagnosis.

28. Device for carrying out the method according to one of claims 1 to 27, comprising a plurality of actuators (1-4) between a travelling mechanism and a vehicle body, a high pressure supply (12) for these actuators (1-4), a low pressure supply (5) for these actuators (1-4), valve mechanisms (1c-4c, 1d-4d) for the selective connection of the individual actuators (1-4) to the high pressure supply (12) or the low pressure supply (5), a measured variable acquisition system for determining measured variables on the vehicle and a computer for obtaining actuation signals for the valve mechanisms (1c-4c, 1d-4d), characterised in that the computer is connected to measured variable acquisition stations of the actuators (1-4), namely actual pressure and length acquisition stations of the actuators (1-4), also to longitudinal acceleration acquisition stations and transverse acceleration acquisition stations, and optionally to vertical acceleration acquisition stations of the vehicle body, in that the computer (11) is designed to calculate first desired pressure values ($P_{desiredI1}$-$P_{desiredI4}$) for the individual actuators (1-4) on the basis of the acquired measured values (z_1-z_4,$P_{actual1}$-$P_{actual4}$,A_x,A_y,A_{z1}-A_{z3}), and

in that the outputs of the computer (11) delivering these first desired pressure values serve for partial vehicle control.

29. Device according to claim 28, characterised in that the respective partial vehicle controller (PFR1) is connected to an actual pressure or/and a length acquisition station of the associated actuator (1) and delivers a second desired pressure value ($P_{desiredIII1}$), in that an overlay unit (summation station B_1) for forming a resultant desired pressure value ($P_{desired-res1}$) from the associated first desired pressure value ($P_{desiredII1}$) and the associated desired pressure value ($P_{desiredIII1}$) is also provided in partial vehicle controller (PFR1), and in that a comparator unit (summation station k_1) for comparing the resultant desired pressure value ($P_{desired-res1}$) and the actual pressure value ($P_{actual11}$) of the respective actuator (1), of which the output controls the valve mechanism (1c, 1d) associated with this actuator (1), is also provided in the partial vehicle controller (PFR1).

30. A method for the active control of the suspension system of a vehicle body as claimed in claim 1, substantially as disclosed herein.

31. A device for the active control of the suspension system of a vehicle body as claimed in claim 28, substantially as described with reference to the accompanying drawings.

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Databases (see over)
(i) UK Patent Office

(ii)

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Documents considered relevant following a search in respect of claims 1 TO 31

Category (see over)	Identity of document and relevant passages	Relevant to claim(s)
	NONE	

Category	Identity of document and relevant passages	Rele ..t to claim(s)

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